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Effect of Various External and Internal Factors on the Carrier Mobility in n-InSe

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Abstract: *The effect of various external (temperature, electric field, light) and intracrystalline (doping, initial resistivity) factors on the mobility of carriers in layered n-InSe semiconductor experimentally have been investigated. Scientific explanations of the results are proposed.*
Keywords: *charge carriers, electrophysical parameters, electronic properties, impurity, mobility, Hall coefficient, drift barrier.*

I. Introduction

In the course of the experimental study of physical properties of complex on chemical composition as well as on energy and (or) crystalline structure semiconductors often theoretically unpredictable physical effects are revealed, which in turn stimulates the development of new theories and practical applications.

One of such semiconductors also is indium monoselenide (n-InSe) related to the class of semiconductor compounds $A^{III}B^{VI}$ of layered structure [1]. The specific crystalline structure of this semiconductor gives it unique electronic (electric, photoelectric, luminescent, optical, etc.) features.

To date many works [2-6] are dedicated to experimental study of physical properties of n-InSe. At that a number of features of these properties have been found those are not explained only in the framework of the relevant theoretical concepts of the physics of quasi-homogeneous crystalline semiconductors [7].

In this paper we report on some kind features of the mobility of the charge carriers obtained by us in this semiconductor. Naturally, the presented experimental results and offered proposals for their scientific explanation, in addition to revealing new features of n-InSe crystals may also be useful in elucidating the mechanisms of different electrophysical phenomena in other spatially inhomogeneous crystalline semiconductors.

II. Experimental Procedure and Samples

The studied samples (clean and lightly doped with some rare-earth elements) were cleaved from different parts of the large single-crystalline ingots, grown by the method described elsewhere [8]. Experimental measurements were carried out at different temperatures (over a range of 77-450 K), intensity (E) of the electric field (from weak to switch voltage [6]), the wavelength (over a range of 0,30-3,00 μm) and the intensity of light (from extremely weak up to $5\cdot10^2$ lx). As introduced impurity dysprosium (Dy), holmium (Ho) and gadolinium (Gd) were used.

III. Experimental Results

When studying the temperature dependence of the specific conductivity, the Hall coefficient and the mobility of the charge carriers it found that the conductivity of different samples of the semiconductor at temperatures below room temperature (T<300 K), depending on their technological origin differ significantly (for different samples varies within $10^{-8}\div10^{-3}$ Sm/cm). Moreover, with decreasing the temperature (T) up to 77K, the value of the Hall coefficient (R_H) almost unchanged and is no different for various samples. In contrast, the value of specific electrical conductivity (σ) and mobility (μ) of the charge carriers in high resistance crystals (σ>10^{-4} Sm/cm at 77K) changes by law $\sigma,\ \mu \sim (-\frac{\Delta\varepsilon}{kT})$ (Fig. 1). The latter allows to say that observed in the low temperature region dependence $\sigma(T)$ in these crystals is not due to the temperature dependence of concentration (n), but is associated with carrier mobility dependence on temperature. However, the experimentally observed dependence of $\mu(T)$ is not subject to the theory of the charge carrier mobility developed for the quasi-homogeneous crystalline semiconductors [6].

At low temperatures also found non-characteristic for quasi-homogeneous crystalline semiconductor features for dependence of the carrier mobility value on specific conductivity (Fig. 2, curves 1 and 2) and on the content of the introduced impurity (Fig.2, curves 3 and 4), as well as on electric field intensity (Fig. 3) and the exposure to light (Fig. 4).

In contrast to low temperatures, in high-temperature region $\mu(T)$ dependence obeys the regularity which is characteristic for quasi-homogeneous crystalline semiconductors with the dominance of the scattering of the charge carriers on acoustic lattice vibrations ($\mu \sim T^{-\frac{3}{2}}$). Under other equal conditions with reduction in the initial (which takes place at 77 K) values of the specific conductivity (σ_0), course of $\mu(T)$ curves approached to predicted by the theory of the mobility of charge carriers in quasi-homogeneous crystalline semiconductors. Effect of doping by rare-earth elements (REE) on μ appears only at low temperatures. At that only at low contents of the impurity (for $N<10^{-2}$ at.%) this influence is evident both in changes in the absolute value of μ, as well as in the curves of its dependence on various external factors (Fig. 2, curves 3 and 4, and Fig. 3, curve 3). It is found, that μ does not depend on the chemical nature of the impurity.

The specificity of the dependence of μ on E in the studied crystals (Fig. 3) lies in the fact that in this case noticeable $\mu(E)$ dependence begins at significantly low values of the electric field intensity and significantly different from the dependence $\mu(E)$, which takes place on heating of charge carriers in a semiconductor by the electric field [9]. In addition, the dependence of the relative change of the carrier mobility ($\gamma = \frac{\mu_E - \mu_0}{\mu_0}$, where μ_0 is the value of the carrier mobility in weak and μ_E in strong electric fields) on the electric field intensity has only a growing character.

The dependence of μ in high-resistivity crystals on the exposure to light also has an interesting character. In this case, firstly, the value of μ in illuminated sample (μ_l) significantly differs from occurring in non-illuminated one (μ_d); secondly, a sign of its change depends on the spectral composition of the light incident on the sample (Fig. 4). In addition, after the cessation of exposure to light the initial value of μ recovers slowly.

IV. Discussion

Going to a discussion of the experimental results, first of all, it should be noted that this results can not be explained from unified position only on the basis of theoretical ideas about the mobility of charge carriers in quasi-homogeneous crystalline semiconductor with a different point scattering centers (lattice vibrations, ions or neutral impurity atoms) [7]. Observed in the experiment activation dependence of $\mu(T)$, as well as the specific features of the effect of light and the electric field on μ together suggests, that at that significant contribution to the impact processes of various external and intracrystalline factors on the mobility of the charge carriers gives some energy barrier. Based on the analysis of existing early works [1-6, 10, 11] on the electronic properties of this semiconductor, we assume that all of these identified specific features of the charge carrier mobility in n-InSe single crystals, primarily are associated with the existence of drift barriers in free energy bands of these crystals, energy heights of those at 77K equal ~ (0.05 ÷ 0.20)eV for different samples. As the temperature increases, and when exposed to the intrinsic absorption light and (or) an electric field of high intensity (when there is a significant injection through current lead contacts in the sample [12]) corresponding smoothing (temperature, light or electric, respectively) these barriers occurs and accordingly increases the value of the charge carriers mobility. As to the nature of these potential barriers, in our opinion, above all, they can be created as a result of spatial heterogeneity of investigated high-resistivity crystals (because of the presence in them random macroscopic defects) caused in the investigated samples due to various reasons (due to stratification, segregation of the composite component atoms during growth, due to the presence of various modifications [1], etc.) which in turn determine the technological origin of the studied sample.

V. Conclusion

- Under otherwise identical conditions, the specific conductivity of the individual samples of single crystals of layered n-InSe semiconductor at T<300 K depending on the technological origin of the different samples varies in the range (10^{-8} ÷10^{-3}) Sm/cm;
- In high-resistivity crystals ($\sigma<10^{-4}$ Sm/cm at 77 K) the dependence of the carrier mobility on various factors has specific features not explained in terms of the theory of the mobility of the charge carriers in quasi-homogeneous crystalline semiconductors;
- These specific features of the carrier mobility in the studied semiconductor directly related to the presence of drift barriers, which formed in free energy bands of the high-resistance crystals because of their spatial in homogeneity.

VI. Figure Captions

Fig. 1. The temperature dependence of the Hall coefficient (R_H) (curves 1-2), specific electrical conductivity (σ) (curves 3-4) and the mobility of the charge carriers (μ) (curves 5-6) in n-InSe single crystals with different initial (available at 77 K) specific electrical conductivity (σ_0).
σ_0, Sm/cm: 1, 3, 5 - $2\cdot10^{-4}$; 2, 4, 6 - $5\cdot10^{-8}$

Fig. 2. The dependence of the mobility of the charge carriers (μ) on initial value of the specific electrical conductivity (σ_0) (curves 1 and 2) and introduced impurity content (N) of REE (curves 3 and 4) in n-InSe single crystals at different temperatures.
T, K: 1 -77; 2 - 300.

Fig. 3. The dependence of the relative change of free charge carriers the mobility (γ) on the electric field intensity (E) in pure (curves 1-4) and in doped with rare earth elements (curves 5 and 6) n-InSe crystals at different temperatures.
T, K: 1, 3, 5 - 77; 2, 4, 6 - 200.

Fig. 4. The dependence of the mobility of the charge carriers (μ) on the intensity (Φ/Φ_m) of light with different wavelength (λ) in n-InSe single crystals.
T=77 K; σ_0 =$4\cdot10^{-8}$ Sm/cm; $\Phi/\Phi_м$= 0,9; λ, μm: 1 - 0.95; 2 - 1.60

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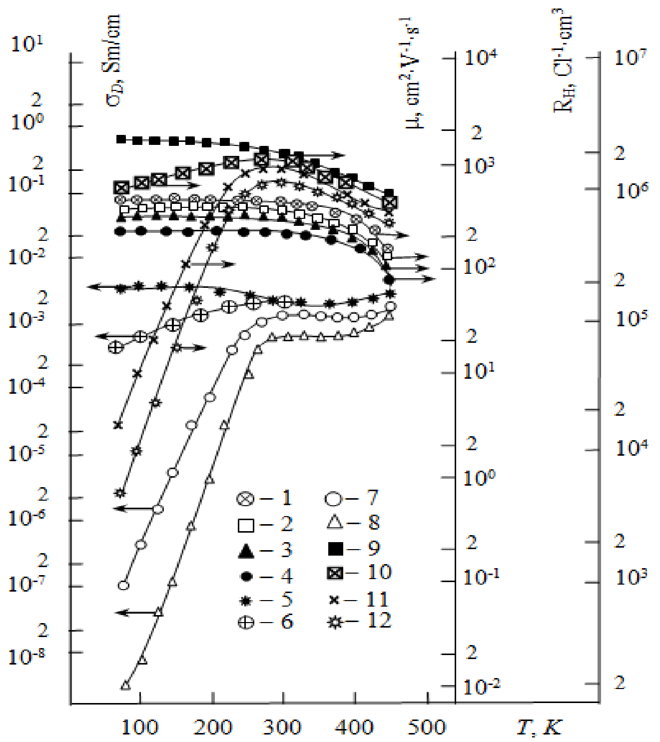

Fig. 1.

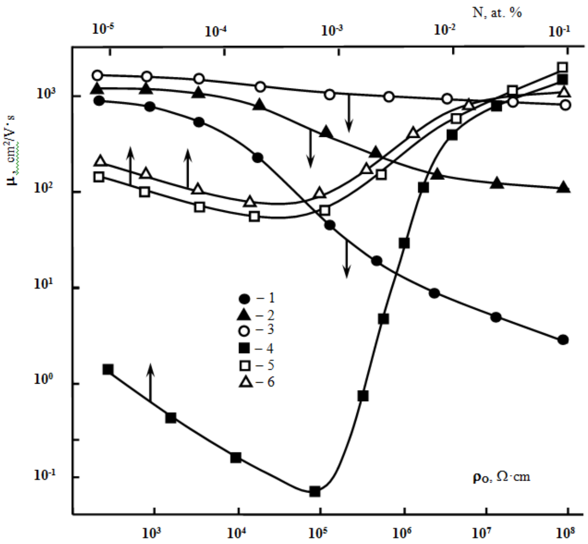

Fig. 2

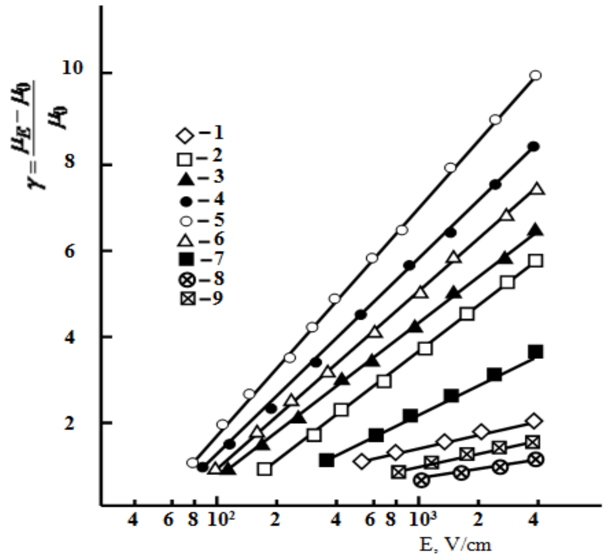

Fig. 3

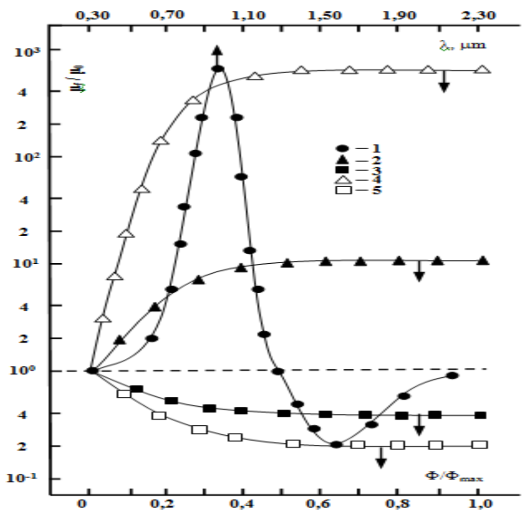

Fig. 4